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(54) [Title of the Invention] Active Matrix Organic Light Emitting Diode Display Device

(57) [Abstract]

[PURPOSE] To provide an active matrix light-emitting display device at a low price in which three-dimensional integration and manufacturing at room temperature of light-emitting elements can be performed.

[Solution] A display device includes a circuit for driving active matrix array of organic light emitting diodes (OLEDs). Into an active matrix OLED display device, a dynamic analog memory which uses an amorphous silicon or polysilicon pass transistor which controls on/off of a driving transistor to supply a constant current to an OLED is incorporated. Unlike an LCD device, an OLED emits light in response to a continuous driving current. A flat panel display device using an OLED circuit is far thinner than a conventional LCD device because a backlight is not needed. Provision of a light-emitting device over an existing circuit allows three-dimensional integration which is impossible with an inorganic LED, so that a structure with an almost 100 percent filling rate can be designed. The active matrix OLED display device can also use a static digital memory which is particularly suited to random access display writing.

[Scope of Claim]

[Claim 1] An active matrix organic light emitting diode display device comprising:

a plurality of pixels which are arranged in two-dimensional array;

a plurality of gate lines which are each connected to pixels of corresponding one row in the plurality of pixels; and

a plurality of data lines which are each connected to pixels of corresponding

one column in the plurality of pixels,

wherein each of the plurality of pixels comprises:

a pass transistor which is connected to a corresponding gate line and transmits a data signal which controls a continuous driving current supplied from a corresponding data line in accordance with a gate signal;

a driving transistor which supplies a continuous driving current to an organic light emitting diode in accordance with the data signal when the pass transistor transmits the data signal; and

the organic light emitting diode which emits light in accordance with the supplied continuous driving current.

[Detailed Description of the Invention]

[0001]

[Technical Field of the Invention] The present invention relates to improvement in display element, method, device, and circuit. Specifically, the present invention relates to an improvement of using an organic light emitting diode (OLED) in active matrix array used for a flat panel display device or the like.

[0002]

[Conventional Art] In a conventional active matrix liquid crystal display (LCD) device, a small interval holding circuit is structured for each pixel for operation. This circuit holds a certain electric charge in an LCD light valve until the pixel is refreshed. Of a plurality of pixels which are arranged in matrix, all the pixels of the same row are charged at the same time in parallel. Upon completion of charging of the pixels of one row, pixels of the other rows are charged sequentially. By repeating this procedure consecutively throughout all of the rows in a display screen, the screen is refreshed

consecutively.

[0003] In a display device, generally, more than one million pixels are used in one display screen in some cases. Therefore, it is important that a setpoint can be loaded into a pixel in a short period in order to refresh the display screen per 16 ms (milliseconds) (i.e., about 60 times per second). Because it takes only several microseconds to write a certain electric charge into a holding circuit, a display screen having 1000 or more rows can be refreshed within 16 ms.

[0004] As for an LCD, use application thereof has been widely found out in the case of using reflected light or transmitted light; however, in many circumstances, a self-light-emitting display device is desirable. In other words, since an LCD device is operated together with a backlight which emits a light beam through an LCD, the thickness of a flat panel display device is increased by the thickness of the backlight. In addition, an active matrix LCD system has a drawback in that light of a light source is absorbed up to 90 % due to a polarization optical system and low aperture ratio and efficiency is low.

[0005] If the backlight is eliminated, the flat panel display device can be far thinner than an existing display device; therefore, it has been demanded to provide a display device with no backlight. Further, it has been also demanded to provide a thinner panel display device which is operated at lower cost of a driver device and at higher efficiency.

[0006] According to "Organic Electroluminescent Devices" Science, Vol. 273, 884 (August 16, 1996), an inorganic LED is seemingly ideal in all points. The inorganic LED has good quantum efficiency, needs a bias voltage only of several volts, can be used for any color, and exhibits very high reliability.

[0007] The inorganic LED has, however, three main problems of cost, integration, and temperature. In an inorganic LED display device, it is necessary that LEDs which are color-matched are assembled and the LEDs are arranged accurately and connected using a wiring. When 5 × 7 pixels are used for each character (therefore, 35 LEDs are used for each color), cost is extremely increased if the number of characters displayed on a display is over about 10 – 15. Further, the inorganic LED generally needs epitaxial growth; therefore, a pixel circuit cannot be overlaid effectively and a device with an almost 100 percent filling rate cannot be obtained. Finally, the inorganic LED is processed at a high temperature which is far beyond room temperature.

[0008] FIG. 15 shows a basic structure of a conventional organic LED 1. An organic film 2 which is at least one layer made of an electroluminescence active material is interposed between two electrodes, i.e., a low work function cathode 6 and a high work function anode 4. The high work function anode 4 is transparent. While a direct current bias is applied, electrons are injected from the cathode 6 into an organic material and holes are injected from the anode 4 into the organic material. Electrons and holes are moved face-to-face and collided with each other by an applied electric field, to form an emission excited state. This energy becomes light ejected through the transparent anode 4. The organic film 2 can be formed by vapor deposition, chemical self assembly, spin-cast, or the like. The thickness of the organic film 2 is in the range of a thickness of several monomolecular layers to about 3000 Å.

[0009] In an application of Norman and the like, US Serial No. 5424560 entitled "Integrated Multicolor Organic LED Array", OLED array formed by providing a negative layer has been disclosed. By patterning a plurality of organic layers of different colors over negative layers, LEDs of plural different colors are formed in a

plurality of regions selected in the array. One transistor which is integrated in the negative layer supplies a driving current to each row of the negative layers when being turned ON sequentially by an external connection pad.

[0010]

[Problem to be Solved by the Invention] However, such an example cited lacks recognition of providing an active matrix light-emitting display device at a low price in which three-dimensional integration and manufacturing at room temperature of light-emitting elements can be performed, or actually has not provided such a device.

[0011] It is an object of the present invention is, therefore, to provide an active matrix light-emitting display device at a low price in which three-dimensional integration is performed easily and manufacturing at room temperature can be performed.

[0012]

[Means To Solve the Problem] In order to achieve the foregoing problem, the present invention provides an active matrix OLED display device which includes two-dimensional array including a pixel electron system including a gate line, a data line, and a pixel. Each pixel includes a pass transistor which receives and passes a data signal from one of the data lines, and a driving transistor which operates in accordance with a data signal from the pass transistor and supplies a continuous driving current in accordance with the data signal to an organic light emitting diode (hereinafter called an OLED). A data signal controls a continuous driving current, and when the driving transistor is operated by the data signal, the OLED receives the continuous driving current and emits light.

[0013] Further, in the present invention, a structure in which a memory means which receives a data signal from the pass transistor and stores the data signal once is provided

is also preferable.

[0014] Each gate line is connected to the pixels of the same row in a plurality of pixels arranged in matrix. Each data line is connected to the pixels of the same column. Therefore, each pixel can be addressed separately by one gate line and one data line.

[0015] Here, each of the above-described pass transistor and driving transistor can be formed of a thin film transistor (TFT).

[0016] Further, another mode of the present invention is characterized in that a continuous driving current flows into an anode of an OLED through a driving TFT and then flows into a common cathode layer connected to all the pixels.

[0017] The first transformation of this mode is characterized in that a continuous driving current flows into a cathode of an OLED through a driving TFT and then flows into a common anode layer connected to all the pixels.

[0018] Further, in the second transformation of the above-described mode, a continuous driving current which flows into a cathode layer through an anode of an OLED and then flows through a driving TFT is provided. Further, in the third transformation, a continuous driving current which flows into an anode layer through a cathode of an OLED and then flows through a driving TFT is provided.

[0019] In the case where a memory means is provided in each pixel, the memory means may be a capacitor which stores an analog data signal. Alternatively, the memory means may be a static cell which holds a digital data signal as long as an element receives electric power.

[0020] Further, another mode of the present invention relates to a method of driving an active matrix OLED display device which includes two-dimensional array including a pixel electron system including a gate line, a data line, and a pixel. According to this

method, for each pixel, a pass transistor is operated by a gate line signal, a data signal is supplied to the pass transistor from a data line, the data signal tansmitted through the pass transistor is stored, the data signal is sent to a driving transistor, a continuous driving current which is supplied to an OLED is adjusted by the data signal, and a light beam is radiated from the OLED.

[0021]

[Embodiment Modes of the Invention] Hereinafter, in order to perfect comprehension of the present invention, preferred embodiment modes of the present invention (hereinafter called embodiment modes) are described using drawings. Note that throughout the drawings, the same reference symbols denote the same parts.

[0022] As described below in detail, the present invention provides a circuit for operating OLED active matrix array with use of an analog or digital memory. If needed, an almost linear luminescence behavior can be satisfied by using existing OLED characteristics. All performance measure receives a benefit from a continuous OLED improvement. By eliminating a lighting system which is needed for an ILD device, a flat panel display device which is far thinner than an existing backlight display device can be provided. Provision of a luminescent layer over an existing circuit allows three-dimensional integration in designing a structure with an almost 100 percent filling rate. This is an advantage over an inorganic LED which generally needs epitaxial growth and therefore cannot realize this type of three-dimensional integration. Monocolor or multicolor operation can be performed by either a front-surface light emission design or a rear-surface light emission design. A layout of a pixel circuit can be optimized depending on various priorities such as the maximum filling rate, a color treatment, manufacturability, or operatability.

[0023] An OLED can now exhibit the luminance (> 10000 cd/m^2) which is over 30 times as large as the luminance of a typical light-emitting display device (300 cd/m^2). Such a rapid development which extends a lifetime of an element has extended a lifetime of an element to over 10000 hours. The electric power consumption per area with 300 cd/m^2 of an OLED is now about 0.04 W/cm^2, which is within the optimum range of electric power consumption for use application of a display device. Further improvement in luminance, durability, and efficiency are expected. For example, the luminance of a display device can be probably further improved by adjusting a solid angle of luminescence with respect to planar microlens array which is overlapped over the whole of the display device.

[0024] Unlike an active matrix LCD device in which the state of a light valve is set by an accumulated electric charge, an OLED emits light in response to a continuous driving current. In order to drive a high-resolution OLED display device, each pixel diode needs to receive a programmable forward bias current through a framing period of the display device. For example, in the case of a 60 Hz display device, the framing period is about 16 ms. With use of an analog or digital memory, the pixel state in the framing period can be stored.

[0025][Embodiment Mode 1] FIG. 1 shows an analog driver circuit according to Embodiment Mode 1, in which a pixel state is stored. Each pixel 102 of an analog driver circuit 100 includes a pass TFT 104, a capacitor 106, a driving TFT 108, and an OLED 110. The pass TFTs 104 of one column are turned ON by a gate line n. When being turned on, the pass TFT 104 of a row n and a column m stores a voltage level from a data line m in the capacitor 106 in the pixel 102. After the pass TFTs 104 of the row n are turned off by the gate line n, a signal of the driving TFT 108, which is

inputted to the gate line n, adjusts a current to the OLED 110 during the framing period. In the analog driver circuit 100, after a current flows into an anode of the OLED 110 through the driving TFT 108, the current flows into a common cathode layer which is connected to all the OLED elements 110 in the analog driver circuit 100.

[0026] If the gate capacitance of the driving TFT 108 is enough for holding a signal throughout a framing period, the capacitor 106 can also be omitted. However, provision of the capacitor 106 has an advantage. The gate capacitance of the driving TFT 108 is, probably, not enough for holding a signal during a necessary period. In addition, when the pass TFT 104 is switched, its parasitic capacitance makes the voltage level of a gate of the driving TFT 108 change, whereby application of an accurate gate voltage becomes difficult. As described above, the further advantage of provision of the capacitor 106 lies in that an effect of the parasitic capacitance is decreased.

[0027] A preferred example of a 4-pixel intersection, used for realizing the analog driver circuit 100 in FIG. 1 is shown in FIG. 2. FIG. 2 shows two metal layers, a polysilicon layer, and circuit contacts. The first metal layer includes anodes 112, 114, 116, and 118, a data line 120, a Vdd line 124, and contacts 126 and 128. The second metal layer includes a gate line 122 and one plate of the capacitor 106. The other plate of the capacitor 106 is formed of the Vdd line. The polysilicon layer includes the pass TFT 104 and the driving TFT 108. The contact 126 connects the pass TFT 104 to the capacitor 106. The contact 128 connects the driving TFT 108 to the anode 118 of the OLED 110.

[0028] This arrangement mode allows a top-gate or bottom-gate TFT to be used as each of the pass TFT 104 and the driving TFT 108. When the capacitor 106 is needed, this capacitor 106 which can be manufactured directly over the Vdd line 124 does not need a

substantive additional area. As mentioned above, this is one advantage of an OLED over an inorganic LED which generally needs epitaxial growth and therefore cannot realize this type of three-dimensional integration. As for an arrangement mode, a layer used for manufacturing, and a processing method of elements, there are many layout transformations which are capable of realizing each circuit described in this specification. The present invention is not limited to the description using FIG. 2.

[0029] The Vdd line 124 can also be provided in parallel with the gate line 122 or the data line 120. In Embodiment Mode 1, in order to minimize the inherent capacitance of the data line 120, the Vdd line 124 is parallel with the data line 120.

[0030] As for the pass TFT 104, it is preferable that a stable gate bias is held in the driving TFT 108 through the framing period. That is, it is preferable that the gate voltage of the driving TFT 108 is stably maintained during the framing period. While another pixel column is driven, the data line to be connected to the pass TFT 104 may be fluctuated. Therefore, during the framing period, an electric charge may leak in the memory cell or out of the memory cell. A voltage error $V_{g\text{-}error}$ can be obtained by the following formula (1).

[0031]

[Formula 1]

$$V_{g\text{-}error} = I_{leakage} \cdot \tau_{frame} / C_{pixel} \ldots (1)$$

Note that $I_{leakage}$ is a leakage current, τ_{frame} is a framing period, and C_{pixel} is pixel capacitance.

[0032] The gray-level resolution may be partially determined by this error. For example, when the voltage of the pixel cell ranges the useful programming range of about 8 V, in order to provide a gray level of 200, the voltage error needs to be

controlled to be better than at least about 40 mV (less than about 40 mV). The leakage current of a transistor can be minimized by narrowing the TFT. For example, a 5 μm × 15 μm polysilicon TFT with a mobility of 30 cm^2/V·sec and a leakage current of 300 fA/μm needs the capacitance of the capacitor 106 of about 0.5 pF. As mentioned above using FIG. 2, the capacitor 106 which can be manufactured directly over or under the Vdd line 124 does not need a further area. Another method for further controlling the leakage of the TFT is to use a double-gate TFT as the pass transistor 104.

[0033] The length of a time usable for writing data into the pixel cell 102 within a framing period of 16 ms depends on a line time of a display device, that is, a selection period of each line. In the case where the width of a display is 480 lines, this time is about 32 microseconds. A period of time of a charging time plus an amplifier settling time needs to be within this time-limit. Generally, in the case of using a polysilicon TFT, a preferable on current can be obtained, and therefore, the charging time cannot be a problem. In the case of using polysilicon, leakage tends to be a main problem for designing a display device. In the case of using an amorphous silicon TFT, the mobility is lower than that of polysilicon when being ON, and the leakage is also lower.

[0034] The pixel cell charging time depends on whether High or Low had been written into the cell at an initial state. Since a gate of an NMOS transistor intrinsically easily transmits a logical "0" (low) state and degrades transmission of a logical "1" (high) state, this asymmetry property is generated. FIG. 3 describes this effect of the pass TFT having the above-outlined charcateristics when data of 0.5 pF is written into the capacitor 106. As shown in FIG. 3, the writing time of a 4 V signal is under 1 microsecond whereas the writing time of a 12 V signal is over 4 microseconds. Either time is enough within the permitted charging time of 32 μs. If a shorter high-level

charging time is needed, an ON voltage of the gate line may be increased. Alternatively, a CMOS bidirectional transistor may be used instead of the NMOS pass transistor 104. In the case of adopting a CMOS, however, the design and process become complicated.

[0035] In the present, an amorphous silicon element and a polysilicon element can be integrated monolithically over the same substrate. According to this, a preferable low-leakage-current property of amorphous silicon for the pass TFT can be combined with a preferable high ON current which can be exhibited by polysilicon for the driving TFT. If the pass TFT 104 is formed of a hybrid of amorphous silicon and polysilicon, the pass TFT 104 can reduce the leakage current enough to reduce the size of the capacitor 106 or eliminate the capacitor 106. However, in order to achieve the charging time comparable to that obtained using the pass TFT 104 of polysilicon, the pass TFT 104 of amorphous silicon with a larger width may be needed. This occupies, of course, a larger are, which may lead to reduction in filing rate of the pixel.

[0036] As one preferable example of the analog driver circuit 100 of an active matrix display device, 72 SPI array of pixels which emit white light at 300 cd/m^2 is used. Each pixel needs a maximum current of about 35 microamperes at 12 V. The requirements of current and voltage can be easily satisfied by using the driving TFT 108 of polysilicon having a size of 30 μm in width and 15 μm in length with a mobility of 30 cm^2/V·sec. This size is only a part of the region of the 72 SPI pixels. Since the pixel size is decreased, the requirement of current, and also the width of the driving transistor are decreased. The occupied area of the transistor can be further optimized to some extent by changing the ratio w/l between width w and length l of the TFT and adjusting a driving voltage of array.

[0037] Obviously, an actual design selection of the size and the driving voltage of a TFT in designing a pixel needs detailed models of TFT and diode characteristics. For example, leakage of the pass transistor is the most difficult parameter to be achieved within specifications, the voltage swing of the data line should be minimized to reduce the leakage. As one method for implementing this, there is a method of increasing the width of the driving TFT 108 in order to reduce the swing of a necessary signal voltage.

[0038] An OLED is, like all of the other diodes, intrinsically a nonlinear element. As for the OLED, a current exhibits dependency on a voltage, and this dependency is almost exponential or almost follows dependency on electric power law. That is to say, a small change in voltage causes a large change in current, and consequently in brightness of the OLED which depends on the bias point of the diode. FIG. 4 shows load line characteristics with respect to several kinds of gate voltages when Vdd of 15 V is applied to 72 SPI pixel array of a typical OLED and a polysilicon TFT having a size of 30 μm in width and 15 μm in length with a mobility of 30 $cm^2/V \cdot sec$. With drain-source voltages of 4 – 12 V, the set point is different from saturation state to linear period of the TFT.

[0039] FIG. 5 shows a diode current I_{diode} and a diode luminance L_{diode} as functions of gate voltage of the driving TFT, in the same condition of that in FIG. 4. Despite nonlinearity of the diode and the TFT, with gate voltages within a desired range of 0 – 300 cd/m^2, the luminance behavior is close to linear with gate biases of 4 - 12 V. This could be very advantageous characteristics in designing a display device since a digital-analog converter used for driving a data line generally generates a voltage swing at a certain voltage interval per gray level. By designing a pixel such that an equal increase in a data line voltage generates an equal increase in light intensity over the

desired luminance range, the gray level of a certain number usable from a data driving electron system can be appropriately used. Therefore, it is shown that this circuit can not only drive the diode at High level or Low level, but also control the grayscale only with a moderate correction.

[0040] FIG. 5 shows another important characteristics. The diode current is increased in accordance with application of a bias, which brings danger of potential burn-in even when the bias error is small. However, the channel resistance of the driving TFT 108 in the ON state preferably functions as protective resistance. This prevents a current flowing through the diode from being exponentially increased. That is to say, the channel resistance of the driving TFT 108 being ON functions as a spike protection function which prevents the current from being exponentially increased in accordance with waveform change of a voltage and prevents burn-in of the diode. Actually, the diode current is increased by less than a linear change when the voltage is over about 5 V.

[0041] The driving TFT 108 can also be manufactured of amorphous silicon. However, the low mobility of an amorphous silicon TFT (0.3 $cm^2/V{\cdot}sec$) means that the driving TFT which is wider, i.e., larger than the case of polysilicon or single crystal silicon is needed. A practical limit to increase the width of a TFT lies in that the TFT occupies large part of a pixel region such that room for the other elements is not left. However, the ON current of the amorphous silicon TFT is high enough to achieve the appropriate luminance in the order of several hundred cd/m^2 enough with the driving TFT of amorphous silicon. Furthermore, as the OLED element becomes more efficient, usage of a smaller driving TFT of amorphous silicon for the diode and a higher luminance can be realized.

[0042] FIGS. 6 to 10 show five types of transformations of the analog driver circuit 100.

[0043] The circuit 100 and a circuit 300 in FIGS. 1 and 6 have an advantage in that one diode contact is separated from the other portion of each circuit in a pixel level and is common with all the diodes. This allows to design so as not to prevent formation of an organic layer and a cathode layer in FIG. 1 or an anode layer in FIG. 6. In addition, this prevents an additional line from being provided in each pixel.

[0044] Analog driver circuits 400 and 500 in FIGS. 7 and 8 are not so preferable in that both ends of the diode are electrically connected to each circuit in a pixel level. This is because not only an additional wiring occupies an additional substrate region but also because each arrangement mode of wirings needs a via (vias or holes) and a contact to be provided by patterning the organic layer and a method for providing the via and the like is not established enough in an organic light emitting diode material.

[0045] Analog driver circuits 600 and 700 in FIGS. 9 and 10 are slightly different from the circuits 100 and 300 in FIGS. 1 and 6. In the analog circuit 600 in FIG. 9, PMOS transistors 604 and 608 are used instead of the NMOS transistors 104 and 108. Similarly, in the analog circuit 700 in FIG. 10, PMOS transistors 704 and 708 are used instead of NMOS transistors 304 and 308. The gate line of the PMOS transistor is set at "high" and is lowered to "low" when data is to be transmitted through the PMOS transistor.

[0046] A PMOS is, as shown in FIG. 9, a technology which is particularly suited to a diode which uses the same cathode in common in a device. This is because the channel conductance of the driving TFT is determined by difference in gate-source voltage and the source side of the TFT is connected to a stable reference voltage. Turning the diode ON does not affect the gate-source voltage. This is in contrast to

FIG. 1 in which the source of the driving TFT is connected to the anode of the OLED. In the case of FIG. 1, voltage drop in the diode in an ON state lowers the gate-source voltage. This is an effect known as "source degeneration". Since the driving TFT is turned ON easier, by designing so as to prevent source degeneration, the same luminance level can be achieved in a display device with a lower signal voltage and a smaller TFT.

[0047] FIGS. 11 and 12 show another two types of transformation examples of the analog driver circuit 100. In analog circuits 800 and 900 in FIGS. 11 and 12, the next gate line n is used for source connection of driving TFTs 808 and 908, that is, the source of each driving TFT is connected to the gate line. As shown in FIG. 11, with use of a gate line, each pixel is opened (selected) of a row corresponding to the gate line, and a current return route through an OLED 810 of the corresponding next row can be formed. Therefore, the gate line n transmits data to the OLED driving TFTs 808 of the corresponding row, and after that, the gate line n becomes low and becomes a current return route of the analog circuit 800.

[0048] For example, providing that the analog circuit 800 shows one pixel in 640-line display device, the gate line n draws a current of the analog circuit 800 in 639 line periods during which the gate line n is low. Although a current and a capacitance reference vary during one line period, the amounts thereof in this period during which an optical output is deviated are nugacious, and do not affect the visibility of a viewer of a display device significantly.

[0049] In the analog driver circuit 900 in FIG. 12, a PMOS transistor 904 and the PMOS transistor 908 are used instead of an NMOS transistor 804 and the NMOS transistor 808 in the analog circuit 800. This is advantageous because a common cathode (it can be

manufactured easily in the present) can be used for the diode. The gate line n of the PMOS transistor 908 is set at high normally and changed to low when data is to be written. Therefore, the gate line n is normally used for supplying a current to an OLED 910.

[0050] In the present, there are hundreds of types of known organic compounds, in addition to a polymer compound and a molecular compound, applicable to an OLED. Since all elements based on these compounds have electrical characteristics which are suitable for excitation by a TFT, the present invention can employ all of such compounds including uninvestigated ones. An OLED of the present invention can use a luminous material such as poly [2-methoxy, 5-(2'-ethyl-hexyloxy)-1,4-phenylenevinylene] (MEH-PPV) or tris(8-hydroxy)quinoline aluminium (AlQ). A hole injecting material such as N,N'-diphenyl-N,N'-bis(3-methylphenyl)1-1'-biphenyl-4,4'diamine (TPD) can also be employed as well as a further electron transporting layer, a dopant, an electrolyte, a buffer layer, or the like. The material such as TPD has electron affinity properties which are suitable enough for the work function of an anode layer formed of indium tin oxide (ITO). Since the ITO can be manufactured to be transparent, the anode side of the OLED 110 is generally a light radiation side. A cathode contact is, for example, an opaque metal conductor such as aluminum, calcium, or magnesium silver. In the case where an OLED display element is structured, the OLED 110 is probably manufactured at the last, and therefore, the analog driver circuit 100 is used in a rear-surface light-emitting display device with a high rate. In this structure, the cathode contact which is potentially fragile and is subjected to breakage is formed as an advantageous continuous layer, and does not need patterning in a pixel layer. The analog driver

circuit 300 in FIG. 6 is advantageous in that a continuous ITO layer with an almost 100 percent filling rate can be provided.

[0051] FIG. 13 shows current routes 150 and 152 which can be used in a continuous anode layer 170 in a front-surface light-emitting display device using the analog driver circuit 300 in FIG. 6. A current flows from an anode to a cathode which is formed for each pixel (the cathode patterned per pixel) through an organic layer, and finally reaches a driving TFT 156 being ON. The pixel driver circuit 300 is formed to have a display region provided with separated islands of exposed cathode contact regions 160, 162, and 164. Then, coating with a continuous electron-conducting layer 166 is performed. If necessary, a further layer (not shown) can also be formed over the continuous electron-conducting layer 166. Then, a continuous hole-conducting layer 168 such as TPD is formed. Further, as the continuous anode contact layer 170, for example, ITO is continuously formed over the hole-conducting layer 168. If the spreading resistance (resistance in a planar direction) of the continuous electron-conducting layer 166 is too low, crosstalk light emission from the next pixel occurs due to the current route 152 shown. One requirement to prevent a mutual effect between the pixels which are next to each other is that the resistance satisfies $R_{172} << R_{174}$. Note that R_{172} is a sheet resistance of the anode contact layer 170 and R_{174} is a resistance between pixels of the electron-conducting layer 166.

[0052] The lateral-direction resistance, that is, the resistance between pixels R_{174} is a very high value due to two reasons. The first is that an organic material is inferior as a conductor and the mobility thereof is low. The second is that each of the continuous electron-conducting layer 166 and the further electron-conducting layer which might be needed is needed to be very thin (that is, < 100 nm) because of its operating principle.

Therefore, such a spreading resistance assures that the continuous anode contact layer 170 can be left without patterning. Therefore, this layout is, of course, suitable for a front-surface light-emitting display device. By enough process controlling and using an appropriate mask set, a front-surface light emission design can provide an element with an almost 100 percent filling rate in which an OLED is arranged over each pixel circuit shown in FIGS. 2, 7, 11, and 12. By changing the continuous anode contact layer 170 to a cathode material and using an enough mask set, a process suitable for a rear-surface light emission design having a continuous upper electrode using a reflective, semi-transparent, or transparent material can be obtained depending on the employed material.

[0053] [Embodiment Mode 2] FIG. 14 shows Embodiment Mode 2 of the present invention, which uses a digital driver circuit 200 in an OLED pixel 202. The pixel 202 includes a gate line n, a data line m, connection to Vdd and Vss, a pass TFT 204, a single bit SRAM cell 206, a driving TFT 208, and an OLED 210. A binary value of "1" or "0" is stored in the single bit SRAM cell 206 provided in each pixel 202. The single bit SRAM cell 206 is, for example, a static memory cell of a polysilicon NMOS.

[0054] An electric charge lost in the single bit SRAM cell 206 is restored by a flow of an electric charge which passes through a load transistor. The pass TFT 204 is turned ON by the gate line, and a bit value ("0" or "1") on the data line m is written into the SRAM cell 206. The stored bit controls the gate of the driving TFT 208. By turning the driving TFT 208 ON, a current can flow into one OLED 210. When the driving TFT 208 is turned OFF, the OLED 210 is turned OFF.

[0055] This design needs six transistors for one pixel (202) and is not affected by a leakage current. Therefore, this design holds the state of the pixel 202 indefinitely.

Therefore, in Embodiment Mode 2, data can be written into a display device by a random access mode, and a framing cycle can be eliminated. The grayscale can also be displayed by modulating a duty cycle. This design layout can be intensive in a region with use of a larger number of transistors and connections thereof. In the above-described embodiment mode shown in FIG. 14, the NMOS TFTs 204 and 208, NMOS TFTs 212, 214, 216, and 218, and a common cathode are used. It may be, of course, transformed such that a PMOS or a CMOS and a common anode are connected to be used.

[0056] Although the present invention is described in detail in this specification with reference to the certain embodiment modes specifically, the present invention is not limited to these embodiment modes. It is an object of this specification to include any transformation, substitute, and equivalent corresponding to the essence and scope of the present invention defined by the claim. For example, the present invention can be applied to a display device of any type where an image is formed by using a light emitting diode. Such a display device includes in its category a flat panel display device, a flat lighting system, an instrument indicator, a sign, and the like.

[Brief Description of the Drawings]

[FIG. 1] A circuit diagram showing analog active matrix OLED array of Embodiment Mode 1 of the present invention.

[FIG. 2] A diagram showing a preferable layout example of a 4-pixel intersection for realizing the circuit shown in FIG. 1.

[FIG. 3] A graph showing a charging time simulation of a pass TFT.

[FIG. 4] A graph showing load line characteristics with several kinds of gate voltages of an OLED and a driving TFT.

[FIG. 5] A graph including a solution of the load characteristics and plots of a diode current and a diode light emission luminance of FIG. 4.

[FIG. 6] A diagram showing the first transformation of a driver stage of a circuit design of FIG. 1.

[FIG. 7] A diagram showing the second transformation of the driver stage of the circuit design of FIG. 1.

[FIG. 8] A diagram showing the third transformation of the driver stage of the circuit design of FIG. 1.

[FIG. 9] A diagram showing the fourth transformation of the driver stage of the circuit design of FIG. 1.

[FIG. 10] A diagram showing the fifth transformation of the driver stage of the circuit design of FIG. 1.

[FIG. 11] A diagram showing the sixth transformation of the driver stage of the circuit design of FIG. 1.

[FIG. 12] A diagram showing the seventh transformation of the driver stage of the circuit design of FIG. 1.

[FIG. 13] A diagram showing current routes which can be used in a continuous anode layer of a front-surface light-emitting display device.

[FIG. 14] A circuit diagram showing an OLED pixel digital driver circuit of Embodiment Mode 2 of the present invention.

[FIG. 15] A simplified diagram of a conventional OLED.

[Explanation of the Reference Numerals]

100, 300, 400, 500, 600, 700, 800, 900 analog driver circuits, 102 pixel, 104 pass TFT, 106 capacitor, 108 driving TFT, 110, 810, 910 OLEDs, 112, 114, 116, 118 anodes, 120

data line, 122 gate line, 124 Vdd line, 126, 128 contacts, 150 current route, 200 digital driver circuit